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Left ventricular haemodynamics before and soon after saphenous vein bypass graft operation for angina pectoris

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Twenty-six patients with coronary artery disease undergoing saphenous vein bypass grafts for treatment of angina pectoris were studied with preoperative and early postoperative left ventricular haemodynamics at rest and during mild supine leg exercise. In approximately 70 per cent of the 21 patients with a patent graft, a return toward normal left ventricular function during exercise was noted on the basis of the absolute level of left ventricular end-diastolic pressure during exercise, and the relation between change in left ventricular end-diastolic pressure and left ventricular stroke work index during exercise. Though the explanation for lack of haemodynamic improvement in patients with a patent graft is not always clear, inadequate revascularization in terms of the number of vessels involved may be an important factor, in addition to the actual amount of flow in the graft and the preoperative state of the ventricle.

In 1954, experimental studies in dogs by Murray *et al.* demonstrated a technique of anastomosis of a vein graft between the ascending aorta and the distal segment of a coronary artery with a ligature about the proximal vessel. They suggested this procedure as a possible surgical approach to the treatment of patients with coronary artery disease. The first description of the clinical application of the saphenous vein bypass operation in patients with coronary artery disease was in 1969 by Favaloro and by Johnson *et al.* The present study was designed to evaluate the effect of aorto-coronary artery-saphenous vein grafts on left ventricular function at rest and during exercise in patients with coronary artery disease undergoing this procedure for treatment of angina pectoris.

Methods

Approximately 200 patients with coronary artery disease underwent saphenous vein bypass graft procedures at the Mayo Clinic between 1968 and 1970. Preoperative and postoperative studies were made of left ventricular haemodynamics of 26 of these patients at rest and during supine leg exercise as well as angiographic evaluation of the vein graft (or grafts) within 7 months after operation.

The patients were selected only on the basis of having had adequate preoperative exercise studies and of giving their consent for postoperative visualization of the grafts. Patients, however, were given the opportunity to refuse the study after full explanation of the risks and objectives of the procedure. Attempts were made to visualize as many grafts as possible.

This study was carried out early in the total experience of this operation and the surgical staff thought it necessary to visualize as many grafts as possible soon after operation for accurate assessment of the results.

The 26 patients, 24 of whom were men, ranged in age from 35 to 67 years (mean age, 50 years). Because of angina pectoris, all patients were significantly disabled and considered surgical candidates for relief of pain. The postoperative studies were performed 8 days to 7 months (mean period, 38 days) after surgical treatment.

None of the patients had valvular disease, cardiomegaly, or other clinical evidence of congestive heart failure. The patients were fasting and premedicated with 100 mg pentobarbitone sodium given intramuscularly; none had received any nitrates within 8 hours of the study. No medication known to influence left ventricular function was being administered and all patients were ambulatory. All haemodynamic studies were performed at the time of coronary arteriography but before the injection of contrast material.

The methods employed for the haemodynamic studies were identical for each patient during the the studies (before and after operation) and have been reported previously (McCallister *et al.*, 1968,

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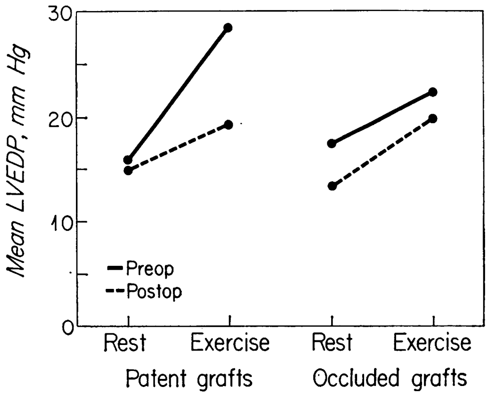


FIG. 1 *Mean left ventricular end-diastolic pressure (LVEDP) at rest and during exercise, before and after operation, in patients with patent and occluded vein grafts.*

TABLE 1 *Clinical and angiographic data*

Case No.	*Extent of coronary artery defect*	*Collaterals*	*Myocardial infarction*		*Vein grafts**	*Interval between operation and study*
			Before operation	*After operation*		
Group 1						
1	5	−	+	−	R	10 dy
2	3	+	−	−	R	10 dy
3	3	+	+	−	R	9 dy
4	1	+	−	−	R	14 dy
5	3	+	+	−	LAD	8 dy
6	2	+	−	−	LAD	10 dy
7	2	−	−	−	LAD	14 dy
8	2	+	+	−	LAD	9 dy
9	4	+	−	−	R and LAD	10 dy
10	3	+	−	−	R and LAD†	4 wk
11	3	−	+	−	R and LAD	13 dy
12	4	+	+	−	R and LAD†	13 dy
13	3	−	−	−	LAD	10 wk
14	2	+	−	−	LAD	5 wk
15	5	+	−	−	R and LAD	9 dy
16	5	+	−	−	R and LAD	12 dy
17	5	+	−	−	LAD	9 dy
18	4	+	−	−	LAD and LC	4 wk
19	4	+	+	−	R and LAD	12 dy
20	5	−	−	−	R, LAD,‡ LC‡	4 wk
21	3	−	+	−	R	5 wk
Group 2						
22	2	−	−	+	LAD†	11 dy
23	2	+	+	−	R†	6 wk
24	1	+	−	−	R†	7 mth
25	3	−	−	+	R†	7 mth
26	2	−	−	+	LAD†‡	4 mth

* Coronary arteries: R = right; LAD = left anterior descending; LC = left circumflex.
† Occluded graft.
‡ Nonselective injection of graft.

1970). Left ventricular and systemic arterial pressures, cardiac output, and heart rate were measured with the patient at rest supine, with the feet raised for 5 minutes on the bicycle ergometer, and after 3 minutes of supine leg exercise at a load of 150 kg m. The cardiac output during exercise was not measured in 4 patients who had angina because they could not continue the exercise for 3 minutes. In 5 other patients, cardiac output could not be measured because of problems with arterial sampling.

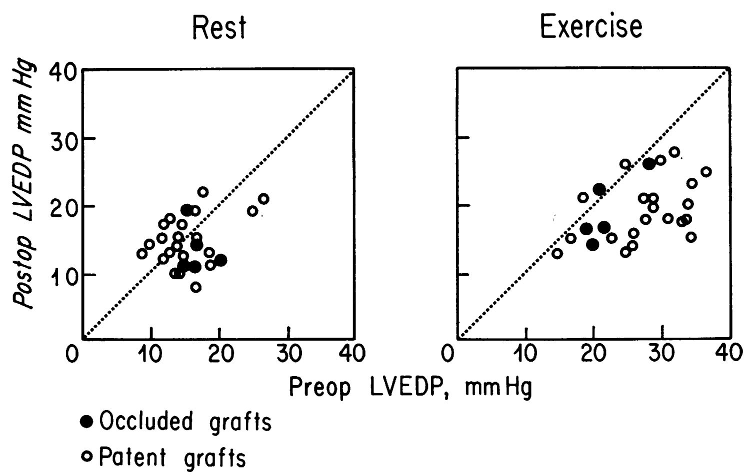
Coronary arteriography and selective injection of meglumine diatrizoate into the vein graft or grafts were performed by the Sones technique. Grading of the extent of coronary disease is that described by Saltups *et al.* (1971). Significant obstructive lesions were based on an estimate of at least a 50 per cent reduction in diameter of the involved vessel. A significant obstruction in the proximal left anterior descending or the left circumflex coronary artery was graded 2, while a lesion distal to the origin of a diagonal or marginal branch was graded 1. A significant obstructive lesion in the right coronary artery was graded 1, while if the left main coronary was involved, the lesion was graded 4.

Eight patients had a graft to the right coronary artery alone, 9 to the left anterior descending alone, 7 to the right coronary and left anterior descending arteries, one to the left anterior descending and circumflex arteries, and one to the left anterior descending, circumflex, and right coronary arteries.

Results

The patients have been divided into two groups depending on the state of the vein graft at the time of postoperative study. In 21 patients (group 1) one or more vein grafts were patent, while in 5 (group 2) all grafts

FIG. 2 *Comparison of preoperative and postoperative rest and exercise on left ventricular end-diastolic pressure.*



were occluded. All 5 patients in group 2 had single grafts.

Table 1 contains clinical and arteriographic data. Tables 2 and 3 list the haemodynamic data for each patient.

Preoperative and postoperative measurements of stroke volume index, mean arterial pressure, and heart rate were comparable in the two groups. In both groups, mean arterial pressure was lower and heart rate was higher at rest and during exercise at the time of postoperative study. Unfortunately there was a difference in the preoperative characteristics of the two groups in relation to changes in left ventricular end-diastolic pressure during exercise. Patients who had patent grafts after operation showed a conspicuous increase in left ventricular end-diastolic pressure with exercise when tested before operation. The effect of operation on the response to exercise was striking in that after operation the patients with patent grafts showed a relatively small increase in left ventricular end-diastolic pressure with exercise (Fig. 1). The group of

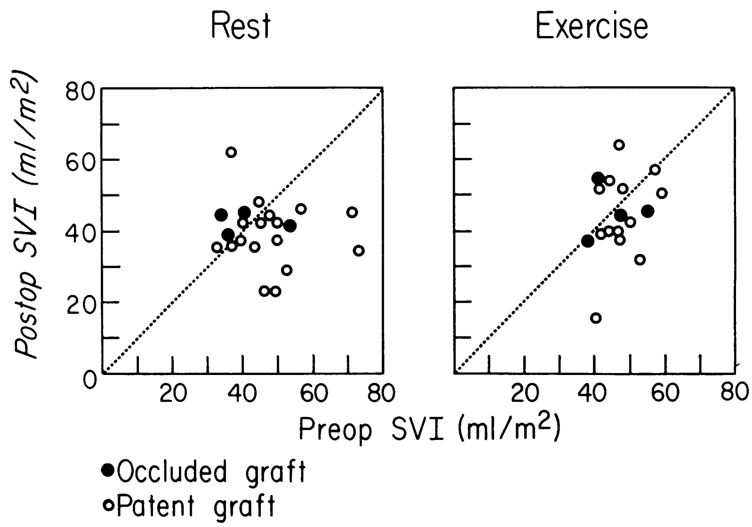


FIG. 3 *Comparison of preoperative and postoperative resting and exercise stroke volume index.*

TABLE 2 *Left ventricular end-diastolic pressure and stroke volume index*

Case No.	*Left ventricular end-diastolic pressure (mmHg)*				*Stroke volume index (ml/m²)*			
	Rest		*Exercise*		*Rest*		*Exercise*	
	Before operation	*After operation*	*Before operation*	*After operation*	*Before operation*	*After operation*	*Before operation*	*After operation*
Group 1								
1	14	22	25	26	37	62	47	64
2	27	21	37	25	45	42	48	51
3	14	10	26	14	45	48	59	50
4	19	13	26	15	41	42	41	52
5	14	15	23	15	71	45	50	42
6	12	12	17	15	45	—	44	—
7	15	12	25	13	56	—	60	—
8	19	11	31	18	50	37	51	—
9	12	15	29	21	49	23	—	27
10	12	17	28	21	33	35	—	44
11	15	17	29	20	50	—	47	—
12	9	13	15	13	53	29	42	39
13	16	19	32	28	50	42	44	53
14	17	15	34	13	48	44	47	38
15	13	18	30	27	46	23	40	15
16	14	14	28	18	37	36	46	39
17	26	14	39	22	73	34	53	31
18	10	14	19	21	57	46	57	57
19	13	13	33	18	44	35	—	36
20	14	10	34	15	—	28	—	36
21	25	19	34	22	39	37	43	39
Mean	16	15	28	19	48	38	48	42
Group 2								
22	20	11	20	17	—	31	—	25
23	17	14	21	22	41	45	55	45
24	17	11	22	17	34	44	41	53
25	15	11	19	16	36	38	38	37
26	18	19	29	27	54	41	47	44
Mean	17	13	22	19	41	40	45	41

TABLE 3 *Mean arterial pressure and heart rate*

Case No.	*Mean arterial pressure (mmHg)*				*Heart rate (beats/min)*			
	Rest		*Exercise*		*Rest*		*Exercise*	
	Before operation	*After operation*	*Before operation*	*After operation*	*Before operation*	*After operation*	*Before operation*	*After operation*
Group 1								
1	111	101	113	116	76	60	88	70
2	108	100	109	110	70	80	80	80
3	90	71	109	84	60	80	79	90
4	97	63	108	85	54	60	72	80
5	102	102	117	107	70	85	80	95
6	118*	102*	140*	125*	60	100	78	110
7	107*	107*	145*	127*	50	76	80	84
8	115*	118*	130*	136*	78	80	84	90
9	138*	108*	133*	130*	85	90	85	100
10	142*	160*	190*	200*	60	64	90	96
11	101*	101*	122*	114*	60	90	70	100
12	96	93	103	101	78	92	90	100
13	99	105	118	117	69	60	93	90
14	95	101	98	112	63	75	92	93
15	113	102	118	113	90	90	114	122
16	132	96	143	109	78	84	90	96
17	110	81	123	97	48	104	90	120
18	102	111	119	119	56	76	76	90
19	110	94	111	117	72	90	90	102
20	106	87	120	106	54	72	96	96
21	108	89	119	97	66	68	90	84
Mean	105	93	115	106	67	80	86	95
Group 2								
22	175*	120*	178*	150*	72	84	85	102
23	101	88	110	100	66	65	73	75
24	100	94	111	107	56	55	74	80
25	99	95	113	101	58	65	72	90
26	95	100	117	109	54	78	80	96
Mean	99	94	113	104	61	69	77	89

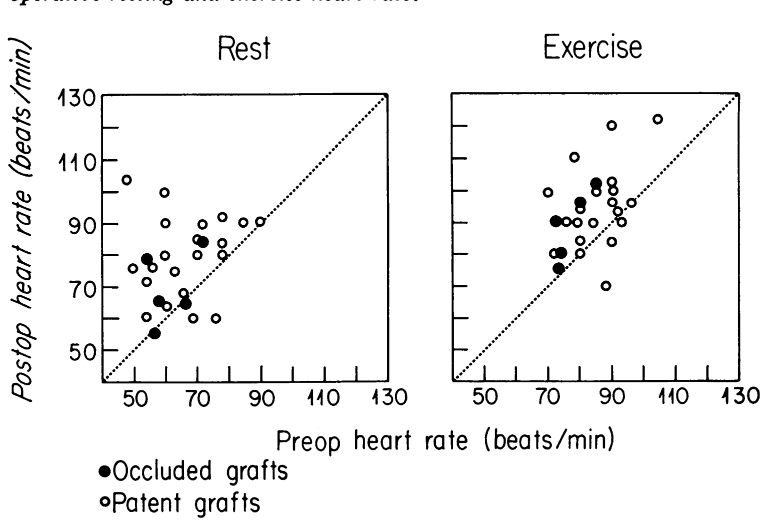
* Peak left ventricular systolic pressure (not included in mean values).

patients with occluded grafts had only small increases in left ventricular end-diastolic pressure during exercise before operation and similar increases when tested after operation. Thus, our results show a positive effect of successful operations when comparing groups of patients with patent and occluded grafts with relation to increases in left ventricular end-diastolic pressure during exercise ($P < 0.001$).

Of more importance than the group means is an analysis of individual patients using each patient as his own control. Considerable individual variation in haemodynamics existed in measurements before and after operation (Fig. 2, 3, 4, and 5). It is noted that there are exceptions to the generalization that patients with patent grafts showed lower levels of left ventricular end-diastolic pressure during exercise when compared with values before operation.

In 15 patients with patent grafts, left ventricular end-diastolic pressures were at least 8 mmHg lower during exercise after opera-

FIG. 4 *Comparison of preoperative and postoperative resting and exercise heart rate.*



tion than before operation. None of the patients with occluded grafts had a similar pattern of response. Of the remaining 6 patients in group 1, 3 patients (Cases 10, 13, and 15) had significant involvement of other coronary arteries not adequately revascularized and in 3 patients the left ventricular end-diastolic pressure during exercise before operation was 20 mmHg or less, indicating less severe impairment of left ventricular function and thus less likelihood of showing improvement.

Fig. 6 shows the relation between the change in left ventricular end-diastolic pressure and left ventricular stroke work index during exercise before and after operation. All 26 patients are not included since some did not have cardiac output measurement for the reasons stated previously. Most of the patients with a patent graft showed improvement in left ventricular function. All patients with an open graft had an increase in left ventricular end-diastolic pressure with exercise greater than 5 mmHg before operation. Nine of these patients exercised in an identical manner after operation had an increase in left ventricular end-diastolic pressure of 4 mmHg or less with similar or greater increases in left ventricular stroke work index compared to the preoperative study. Three of 4 patients (Cases 15, 17, and 18) with increases in left ventricular end-diastolic pressure of more than 4 mmHg during exercise postoperatively had coronary arteries with significant obstruction and no vein graft established to these vessels. A similar pattern of improved left ventricular function was not observed in the 4 patients with occluded grafts.

Discussion

The problems of assessing results of surgical treatment for angina pectoris in patients with coronary artery disease have been emphasized previously (Dimond, Kittle, and Crockett, 1960). However, in terms of the objective for which the operation is performed, that is, relief of pain, reports regarding results of saphenous vein bypass graft surgery are favourable (Favaloro *et al.*, 1970; Johnson and Lepley, 1970). In spite of this, it does seem important to continue attempts to evaluate objectively the results of such operations. In the early postoperative period, the present study showed a return toward normal of left ventricular function during mild supine leg exercise in approximately 70 per cent of the patients who underwent adequate revascularization by the saphenous vein graft technique. It is significant that this conclusion cannot be reached from evaluation of the resting haemodynamics alone.

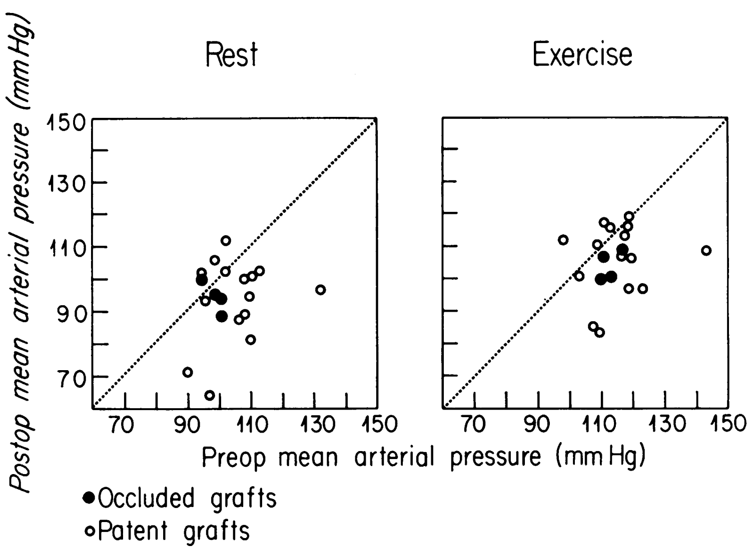
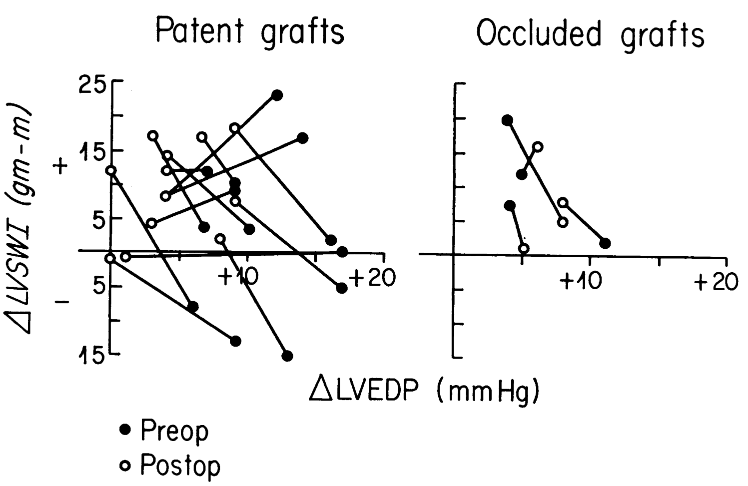


FIG. 5 *Comparison of preoperative and postoperative resting and exercise mean arterial pressure.*

It is difficult to prove at this time that the change in left ventricular haemodynamics during exercise after operation is due to relief of myocardial ischaemia by the flow provided through the vein graft. The application of roentgen videodensitometry to the measurement of flow in the vein grafts should provide

FIG. 6 *Relation between change in left ventricular end-diastolic pressure and stroke work index before and after operation in patients with patent and occluded grafts.*



a more precise method of evaluating response to surgery (Smith *et al.*, 1971). Thus, though patients may have patent grafts, the flow may be somewhat low. This phenomenon may explain why the haemodynamics in some of the patients in group 1 did not improve. Ample experimental data in animals, however, show abnormal left ventricular function with myocardial ischaemia and the reversible nature of such changes when the ischaemia is relieved (Sarnoff, 1955; Tatooles and Randall, 1961; Tennant and Wiggers, 1935). It is recognized that many factors may influence the left ventricular end-diastolic pressure. Consideration must be given to the possibility that the apparently improved performance of the left ventricle after operation in the present study is a nonspecific one related to the postoperative period of rest in bed, a different haemodynamic state, or other unknown factors. This result seems unlikely in view of the absence of similar changes in patients with occluded grafts. Study of more patients with occluded grafts could obviously strengthen this point. Eleven of the 15 patients with left ventricular end-diastolic pressure during exercise of at least 8 mmHg less than preoperative values had mean arterial or peak left ventricular systolic pressures within 16 mmHg on comparison of values during exercise before and after operation. Thus, it seems unlikely that the lower left ventricular end-diastolic pressure during exercise is due solely to a reduced afterload at the time of postoperative study. Further study of these patients, a year or more after operation, is planned, however, to help in assessment of this early observation.

Quantitative data on the analysis of left ventriculograms in the present group of patients are not available. However, surgeons (Favaloro *et al.*, 1970; Johnson and Lepley, 1970) have described changes in the appearance of ventricular contraction at the time of operation subsequent to successful vein bypass grafts, and recently several groups (Campeau *et al.*, 1970; Rees *et al.*, 1970) have reported improvement in quantitative indexes of left ventricular function determined by analysis of left ventriculograms.

The relation between these observed haemodynamic changes and the future clinical state of the patient is not clear. Additional studies with careful clinical follow-up at yearly intervals after these surgical procedures are planned to help clarify this point. Similar haemodynamic studies of patients a year after implantation of an internal mammary artery for relief of angina pectoris have been reported. In the majority of these patients, haemodynamic evidence for improved left ventricular function was lacking (McCallister *et al.*, 1970).

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